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## GENERAL REVIEW

# Filling bone defects with $\beta$ -TCP in maxillofacial surgery: A review



## *Comblement osseux par $\beta$ -TCP en chirurgie maxillofaciale : revue des indications*

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### MOTS CLÉS

$\beta$ -TCP ;  
Biomatériau ;  
Grefe osseuse ;  
Sinus lift ;  
Tri calcium phosphate

**Summary** Reconstruction of bone defects prior to implant placement now involves synthetic substitutes such as  $\beta$ -TCP because of its ability to promote bone remodeling. Its capacity to be progressively substituted by the patient's bone allows to regenerate a dense bone volume. In addition, its availability in large quantities, avoiding the morbidity observed with harvesting autogenous bone, widens the operative indications. In this paper, the main indications of  $\beta$ -TCP in maxillofacial surgery (dentistry, parodontology and dental implant surgery) are reviewed. They include periodontal bone disease, bone disjunction, pre-implant surgery (sinus floor elevation and lateralization of the inferior alveolar nerve).

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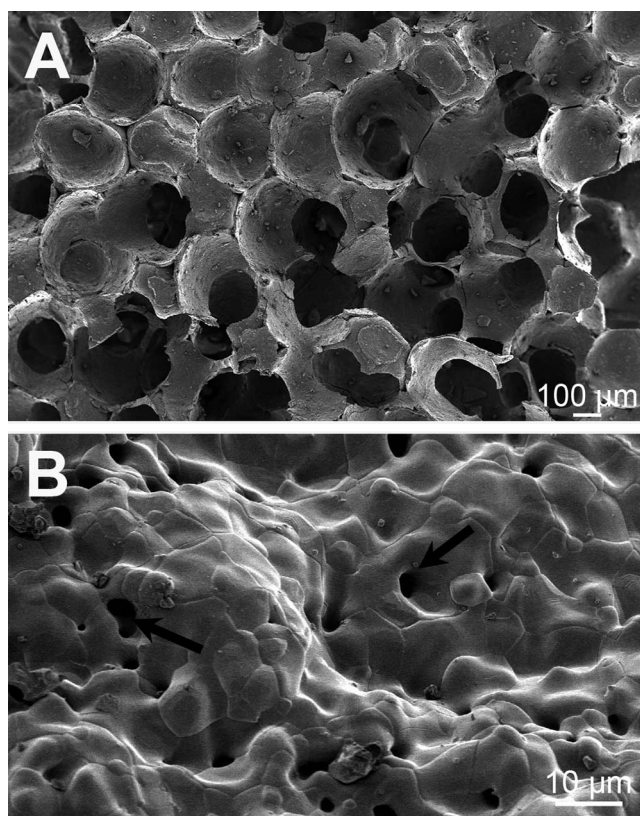
**Résumé** La reconstruction des déficits osseux avant la pose d'implant fait appel désormais à des matériaux de substitution synthétique comme le  $\beta$ -TCP de par ses capacités à favoriser le remodelage osseux. Il est progressivement substitué par l'os du patient permettant de régénérer un volume osseux dense. Enfin, sa disponibilité en grande quantité, évitant la morbidité liée à un site de prélèvement d'autogreffe, élargit les indications opératoires. Dans ce travail, les principales indications d'utilisation du  $\beta$ -TCP en chirurgie maxillofaciale (chirurgie dentaire, parodontologie et implantation dentaire) sont revues. Elles comprennent la maladie osseuse parodontale, la disjonction osseuse, la chirurgie pré-implantaire (élévation de sinus et latéralisation du nerf alvéolaire inférieur).

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## Introduction

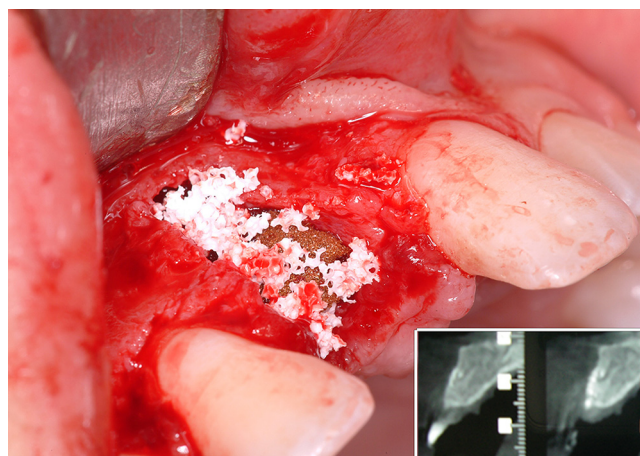
In dental and maxillofacial surgery, the repair of bone defects aims at recreating a bony site that is suitable for

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**Figure 1** Scanning electron microscopic image of beta-tricalcium phosphate ( $\beta$ -TCP). A. A scaffold suitable for bone grafting with an interconnected macroporosity. B. High magnification of the surface of a wall of this scaffold showing the typical surface of sintered grains with microporosity (arrows).

morphological, prosthetic or implant-prosthetic rehabilitation [1,2]. Causes of bone deficiency are numerous: genetic, post-traumatic, secondary to tooth removal, infectious or iatrogenic. The volume of bone to reconstruct varies according to the anatomical situation. The characteristics of the

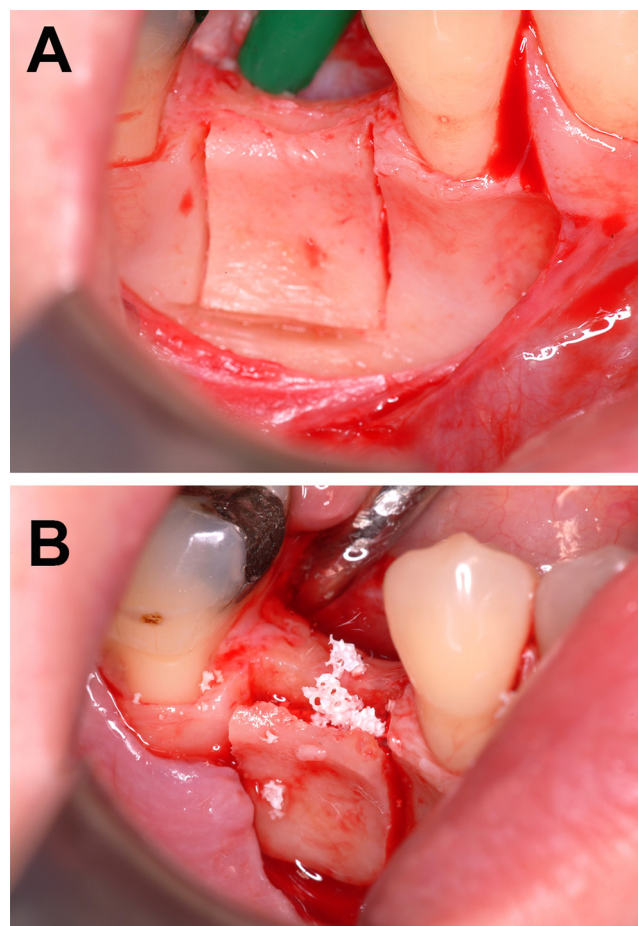


**Figure 2** Filling a bone socket and reconstruction of the cortical side with beta-tricalcium phosphate ( $\beta$ -TCP) granules after a tooth extraction. Insert: CT analysis of the reconstructed bone several months after the graft, note the high bone density.

graft depend on the volumes to be filled (alveolar area) or to be restored (vertical or horizontal ridge insufficiency, bone cyst or sinus lifting). The volume and form of the defect influence the choice of the grafting material. A considerable number of possibilities are available: e.g., harvesting autologous bone particles to fill a post-extraction socket [3], thickening of a thin ridge caused by hypodontia [4], bone disjunction [5], sinus lifting [6] or lateralization of the inferior alveolar nerve [7]. Surgical techniques also use various surgical protocols with a local or a general anesthesia; it should be noticed that local anesthesia is being practiced more and more frequently. Although autologous bone grafts and allografts have been a recognized surgical modality for several decades, the use of synthetic biomaterials has continued to develop as substitute products, especially in the context of pre-implant surgery.

### Definitions of graft-related criteria

A bone substitute must be biocompatible and fill several criteria: bio-inertia is defined as the absence of physico-chemical reaction of the product in direct contact with bone. Bioactivity is the capacity to develop reactions favoring osseointegration of the product and the adaptation of the



**Figure 3** A. Disjunction on a premolar zone. B. Beta-tricalcium phosphate ( $\beta$ -TCP) granules (1000–2000  $\mu$ m) with high porosity are inserted in the gap created between the two cortices.

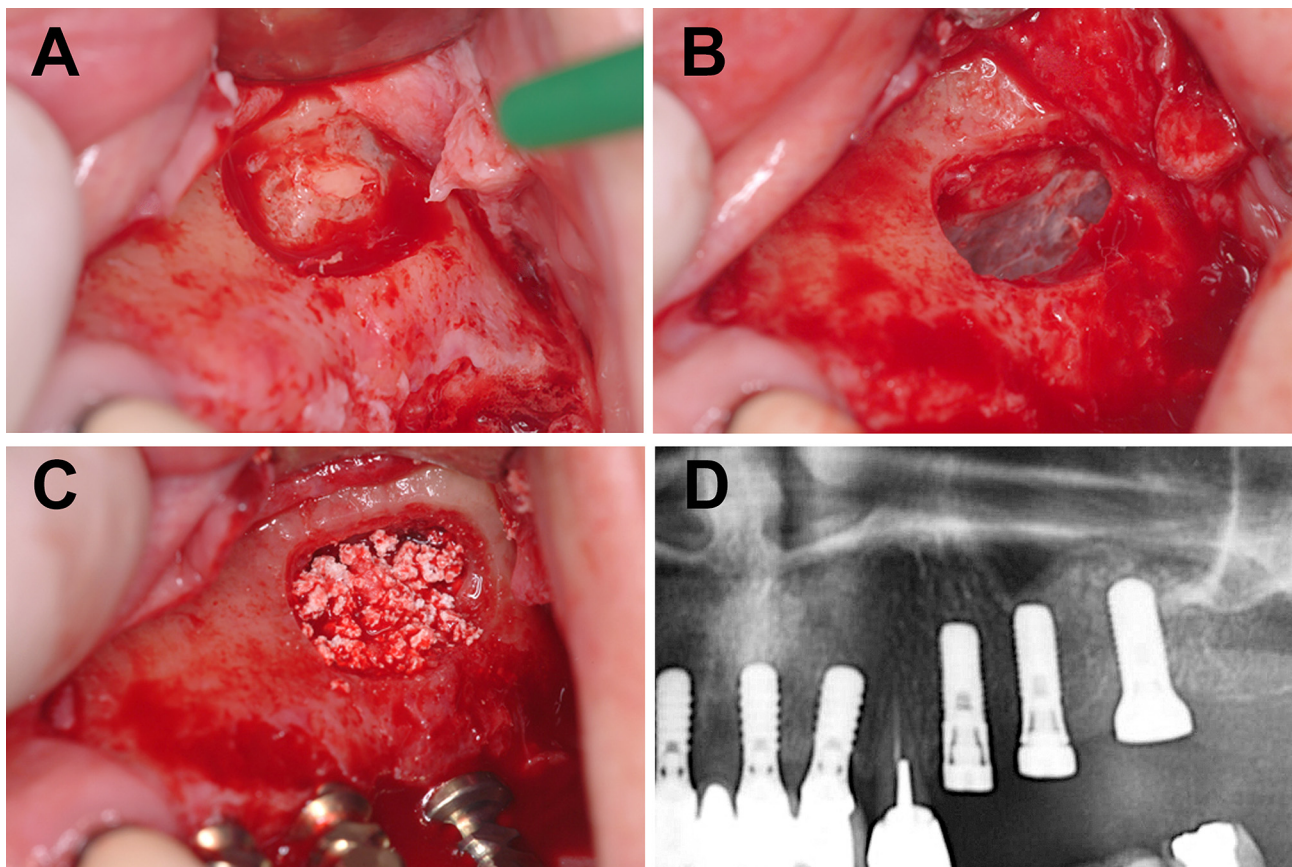


receiving tissue. Osteoinduction is defined as the ability to induce bone formation in an extra-skeletal area. Osteoconduction is the ability of the recipient bone cells to colonize the graft. An evolution in the choice of materials to fill bone defects occurred in the past few years. Autologous graft is considered as the "gold standard" in terms of osteogenicity but its main disadvantage is that obtaining a sufficient volume of bone is sometimes a problem (except when large bone samples are harvested but with a significant increase in morbidity) [8,9]. So, due to the justified reluctance to use extra-oral bone grafts and the medicolegal constraints, the interest for synthetic bone substitutes is increasingly growing. Most surgical teams seek to restore sufficient amounts of high quality bone allowing implant placement by using biomaterials to restore a part or the whole bone. Beta-tricalcium phosphate ( $\beta$ -TCP) is now one of the most used synthetic materials for bone reconstruction in orthopedic and maxillofacial surgery and now in pre-implant surgery. In implantology, the resorbable or non-resorbable nature of the grafted material appears of the utmost importance. Some materials are resorbable but there are considerable differences in term of disappearance upon time, some of them can persist indefinitely. The use of a biomaterial in a maxillary or mandibular site after a tooth extraction must allow implant placement in a second surgical time. In addition, synthetic biomaterials preserve the macroarchitecture

of the implanted areas and they can be produced in large quantities by industry.

### Characteristics of $\beta$ -TCP

$\beta$ -TCP -  $\text{Ca}_3(\text{PO}_4)_2$  - belongs to the family of tricalcium phosphates in the beta phase. Being considerably much more resorbable than hydroxyapatite, this biomaterial is highly biocompatible when implanted in bone; it is resorbable within 6 to 9 months as shown in animal and human histological studies [10]. One of the main characteristics of the biomaterial is to be commercially available as scaffolds with a macroporosity of 100 to 600  $\mu\text{m}$  that ensures osteoconduction and can reach 85% of the total mass of the grafted material (Fig. 1A).  $\beta$ -TCP has also a microporosity ( $< 100 \mu\text{m}$ ) due to sintering of elementary grains, which facilitates the exchange of extracellular fluxes of  $\text{Ca}^{2+}$  and  $\text{PO}_4^{3-}$  ions (Fig. 1B). This ensures an optimal bone remodeling with increased osteoblastic apposition and the apposition of lamellar bone. Its biocompatibility, its bioresorption and osteoconductive properties from the recipient bone make it a reliable material particularly adapted to fill alveolar sockets of variable sizes. In addition, reconstruction of a maxillary sinus in a pre-implantation step can also be easily obtained.  $\beta$ -TCP can also be prepared in the form of plates



**Figure 4** Sinus lift elevation. A. The sinus membrane is gently pushed away. B. The space available for grafting is then exposed. C. Beta-tricalcium phosphate ( $\beta$ -TCP) granules (1000–2000  $\mu\text{m}$ ) with a high porosity are used to fill this area. D. Implants have been placed in the grafted area 9 months later, note the increase density of the grafted zone.

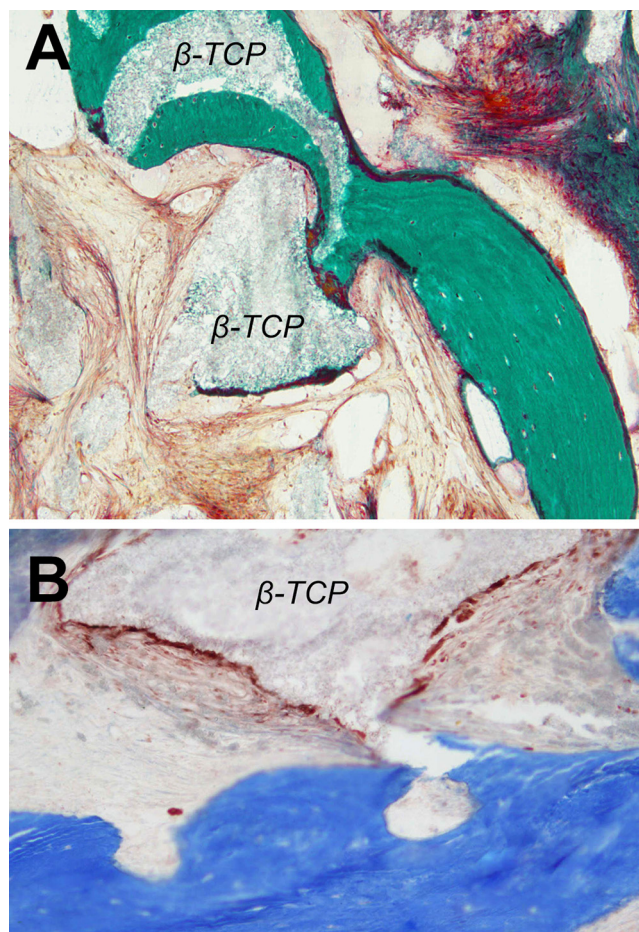
to fill the sinus ceiling. Such plates also allow to densify the underlying graft with granules and can be used to protect the sinus mucosa (Schneider's membrane) in case of perforation.

## Clinical indications of bone filling biomaterials

### Periodontics and pre-implant surgery

#### Periodontal bone disease

It has been proposed for more than 15 years to fill periodontal pockets with biomaterial granules. Loss of the peri-radicular bone tissue induces mobility of the dental root and can cause loss of the tooth. Under local anesthesia, the procedure consists in detaching the full thickness of the gingiva to scrap the inflammatory tissues and cementum along the root and to fill the defect.  $\beta$ -TCP is available in various granule sizes varying from 550–1000  $\mu\text{m}$  to 1000–2000  $\mu\text{m}$ .



**Figure 5** Histological analysis of a bone biopsy harvested in a patient six months after grafting with beta-tricalcium phosphate ( $\beta$ -TCP) granules. A. Mineralized bone is apposed directly onto the biomaterial surfaces. (Goldner's trichrome, calcified bone is in green osteoid tissue in red). B. Remodeling of implanted  $\beta$ -TCP granules by osteoclasts. Histochemical identification of these cells by their tartrate resistant acid phosphatase (TRAcP) content; osteoclasts are in brown, newly apposed bone is counterstained in blue and  $\beta$ -TCP remains unstained.

The characteristics of  $\beta$ -TCP scaffolds prepared with a high porosity by industry are to promote reconstruction with lamellar bone. In case of apicoectomy and elimination of the cystic tissues at the apex of the tooth, a bone loss may occur with a variable volume ranging from a few  $\text{mm}^3$  to 1 or 2  $\text{cm}^3$ . The cystic tissue is removed by a careful curettage and 1000–2000  $\mu\text{m}$  granules of high porosity  $\beta$ -TCP are used to fill the cavity.

#### Pre-implant surgery

Increasing the volume of the dental arch will allow the placement of dental implants. In implant surgery, it is often mandatory to respect the healing time necessary for the grafted area to be remodeled before placing an implant in a bone environment that is sufficient in volume and will remain stable over time. Post-extraction sockets, as periodontal pockets, can benefit from the use of  $\beta$ -TCP granules to support bone reconstruction (Fig. 2).

#### Bone disjunction

Whether at the maxilla or the mandible, insufficient thickness of the ridge imposes to recreate the bone thickness. Apposition graft is an alternative technique but requires a second site to harvest the autogenous bone; sometimes this is not possible or rejected by the patient. Bone disjunction represents in fact a greenstick fracture [11]. With a bone chisel or with a fissure burr, vertical sections are done at the desired height (Fig. 3A). Similarly, a cleavage plane is made in the whole thickness of the ridge. Finally, the cortical bone is gradually moved away while maintaining its apical insertion. The gap (4 to 5 mm in thickness) is then filled with  $\beta$ -TCP 1000–2000  $\mu\text{m}$  granules, this prevents the vestibular cortical bone from returning in place (Fig. 3B). This allows bone remodeling and osseointegration of the biomaterial by osteoconduction in 8 to 9 months.

#### Sinus floor elevation

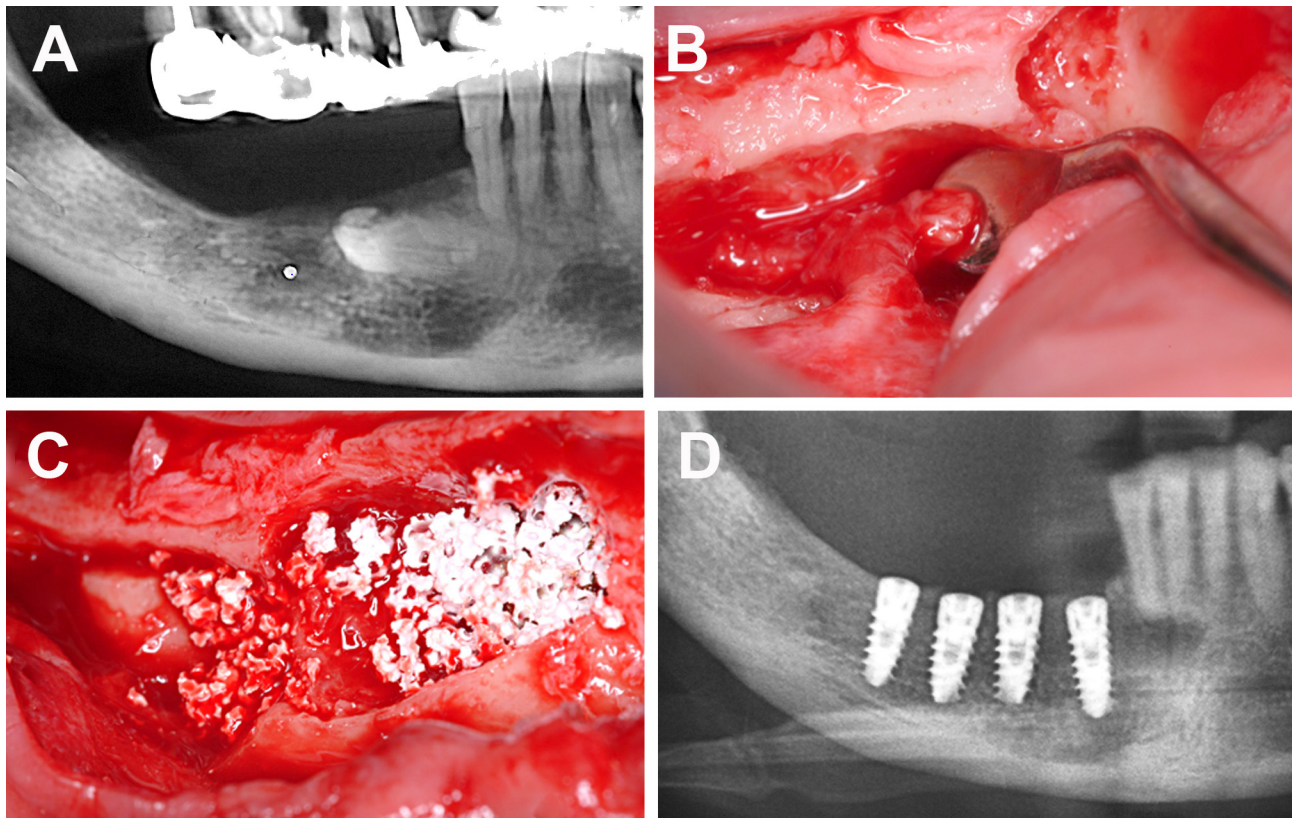
Placement of an implant in the posterior zone of the upper jaw is often challenging because bone loss is observed in most patients with edentulation and thickness of the sinus floor may be reduced up to 5 to 6 mm. It is evident that such a reduced vertical bone height limits implant placement since an 8 to 10 mm of bone height is required to allow implant placement. Thus, elevation of the maxillary sinus floor is a recently described solution to restore a suitable 5 to 10 mm height of available bone for implant placement. Sinus lifting was first reported by Boyne and James in the 1960s [12]. Sinus floor elevation for dental implant placement is obtained by detachment of the sinus mucosa using a lateral maxillary window approach (lateral anastrotomy, in most cases) or by the crestal route, followed by the filling by a grafting material [13–15]. A crestal incision of the maxilla is made on the alveolar ridge with a vertical discharge incision in the canine region and opposite to the posterior tuberosity. The gingival flap is then reclined to ensure good visibility of the anterior surface of the sinus and allow the realization of a bone window whose upper limit is 15 mm from the crest. The bone window is done with a diamond round bur under irrigation (Fig. 4A). The central trapdoor of cortical bone is preserved to maintain a bone layer for



the mucosa during the other surgical steps. The sinus membrane is then gently raised from the bone floor to delimit a sufficient volume. At this stage, one should carefully check the presence of any perforation of the membrane because they can lead to complications at the time of placement of the biomaterial (Fig. 4B). A suture may be done with a 6/0 thread or a  $\beta$ -TCP plate (Sinus-up™, Kasios, France) to ensure a complete closure of the sinus. The cavity is then filled with a biomaterial that will latter provide the bony bed suitable for implant placement. Autogenous bone chips have long been considered as the gold standard due to their presumptive maintenance of cellular viability [12]. The choice of a biomaterial must fulfill several qualities: it should be biocompatible in the grafted site and should not induce an inflammatory reaction of the sinus mucosa, which could be deleterious to the whole surgical procedure. It must be integrated within the grafted areas by combining its resorption and its substitution by new bone. Resorption should be progressive to allow bone remodeling with apposition of lamellar bone. Non-resorbable hydroxyapatite should be avoided [16]. Macroporosity of the grafted biomaterial plays a key role in bone osteoconduction because it determines the invasion of vascular and cellular sprouts [17,18]. Lastly, the grafting material must be provided in sufficient volume to allow an easy adaptation in these complex surgical areas to fill volumes up to 3 to 6 cm<sup>3</sup>. Over the years, several types of materials including allografts and xenografts of various

origins have been used either alone or mixed with morcelized autogenic bone [19].  $\beta$ -tricalcium phosphate was the first synthetic bone substitute to be proposed for sinus floor elevation [14]. The use of 1000–2000  $\mu$ m granules of high porosity  $\beta$ -TCP HP is recommended nowadays [20]. Antral filling begins by placing granules on the posterior wall then on the latero-anterior and anteroposterior walls without excessive compression of the biomaterial (Fig. 4C). The anterior wall is then filled and a resorbable Surgicel™ membrane (Ethicon, Johnson and Johnson) to avoid migration of granules and sutured with Vicryl 5/0™ thread (Ethicon, Johnson and Johnson). A computed tomographic analysis is usually done 8 months later. There is a marked densification of the grafted area filled by the biomaterial and no edema of the sinus membrane can be evidenced (Fig. 4D).

The grafted area appears to be more radio-opaque than the surround bone tissue (due to the greater calcium content of  $\beta$ -TCP). The density will progressively decrease as the biomaterial is replaced by bone [21]. Histological analysis confirmed the direct bonding of mineralized bone matrix to  $\beta$ -TCP granules together with the biomaterial resorption (Fig. 5A) [10,22,23]. Depending on the area, the bone has a matrix of lamellar or non-lamellar texture. The detection of a key enzyme present in the osteoclasts (tartrate resistant acid phosphatase [TRAcP]) evidences these cells at the surface of the newly formed bone and at the surface of  $\beta$ -TCP granules (Fig. 5B).



**Figure 6** Lower alveolar nerve (IAN) lateralization. A. X-ray of a patient with an included canine whose ablation will create a large bone defect. B. A significant bone defect is obtained and the emergence of the IAN is evidenced. C. Beta-tricalcium phosphate ( $\beta$ -TCP) granules (1000–2000  $\mu$ m) with a high porosity are used to fill this area. D. X-ray of the patient after lateralization of the IAN and placement of four implants is now possible.

## Lateralization of the inferior alveolar nerve (IAN)

Vertical atrophy of alveolar ridge is encountered at the mandible as a sequela of dental extractions (Fig. 6A) or in patients with a long history of wearing a removable prosthesis. An onlay graft allows bone reconstruction in the vertical direction but requires the use autologous cortico-trabecular bone harvested at the calvarium, iliac crest, tibia or mandibular symphysis, retromolar area, mandibular ramus [24]. The use of allogenic or xenogenic bone particles has also been suggested. In all cases, the graft is maintained to the alveolar ridge by osteosynthesis using titanium screws. The IAN remains one of the main anatomical limitation to the placement of implants in the posterior mandibular zone. Another alternative is to move the IAN laterally from its canal by nerve lateralization and repositioning to provide a bone area suitable for implant placement [25]. The displacement of the IAN can be proposed in several situations: in case of compression of the nerve sheath following a trauma, when a removable prosthesis exerts compressive strains on the IAN or when an implant apex directly compresses the nerve [7,11,26]. Lateralization of the IAN radically changes the nature of the prosthetic concept where only the anterior region is usually concerned. Displacement of the nerve allows the placement of implants in the posterior zone with a removable prosthesis with an O-ring system or a posterior bar. In fixed dental prosthesis, the posterior implants increase the holding of an overdenture or a fixed bridge by providing supporting pillars. In case of a removable prosthesis, attachment of the prosthesis is considerably improved when an O-ring system or a posterior bar is used.

The surgical technique is based on a vestibular osteotomy of the external cortical bone in front of the mental foramen, and extended by fashioning of a bone flap towards the rear [27–29]. The cortico-trabecular bone block is removed to gain access to the nerve and to gently tease it out of the mandible (Fig. 6B). The bone block is both removed *in toto* or morcellized and kept until the end of the intervention. Replacement of the bony flap allows an underlying bone growth and prevents the nerve from returning to the mandibular canal. Nevertheless, displacement of the IAN creates a bone void. It can be filled with  $\beta$ -TCP particles (Fig. 6C) held in place with a Surgicel<sup>TM</sup> membrane. Compact blocks of  $\beta$ -TCP can also be implanted. After an 8-month bone healing period, the mandibular bone has been reconstituted and offers a suitable site for implant placement (Fig. 6D). High porosity  $\beta$ -TCP granules plays an essential role in the local remodeling of bone volume and lead to the formation of a quality site.

## Conclusion

Bone remodeling is an essential step in the healing process of a grafted area. The contribution of synthetic biomaterials is now confirmed and guarantees an optimal reconstruction that allows implant placement in a second step. The availability of  $\beta$ -TCP in the form of granules or compact slabs offers new therapeutic perspectives in maxillofacial and pre-implant surgery.

## Disclosure of interest

The author declares that he has no competing interest.

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